TECHNICAL NOTES

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

No. 432

DRAG TESTS OF 4/9-SCALE MODEL ENGINE NACELLES

WITH VARIOUS COWLINGS

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SUMMARY

Results are given for drag tests of 4/9-scale model radial air-cooled engine nacelles made as a part of a general investigation of wing-nacelle-propeller interference. A small nacelle of the type commonly used with exposed engine cylinders was tested with various forms of cowling over the cylinders. The effects of cowling-ring position and of angle of ring chord to the thrust line were investigated. An N.A.C.A. cowled nacelle and a smooth body were also tested.

The results are given at 50, 75, and 100 miles per hour for -5°, 0°, 5°, 10°, and 15° angle of pitch.

INTRODUCTION

Models of two air-cooled engine nacelles with various cowlings have been tested in the propeller-research tunnel of the National Advisory Committee for Aeronautics as a part of a general investigation of wing-nacelle-propeller interference. Although the addition of nacelles to an airplane generally introduces interference problems, it is considered advisable to give the results of the drag tests of the nacelles alone without interference in this report as a contribution to general information on aerodynamic resistance. It should be borne in mind that these results were obtained with the propeller removed. The reader is referred to the reports on the general program (reference 1 and others to be published in the near future) for the practical application of nacelles to airplanes. (See also references 2, 3, and 4.) The results of drag tests on a number of small model nacelles are already available. The close check of two of the 4/9-scale combinations tested with full-scale results gives assurance that the values

obtained for the other combinations, especially with the
ring cowlings, should be close to those for the full-scale
condition. This check is attributed to the large scale
(4/9) of the present models and the fairly accurate repro-
duction of engine details.

Two nacelles were used. The first was similar to the
conventional types which have exposed cylinders; the second
was a larger one which, when used with a hood, constituted
an N.A.C.A. cowled nacelle. Both nacelles were 4/9-scale
models of Wright J-5 engine nacelles reported in reference
3, and were tested with various types of cowling over the
engine, which was reproduced in considerable detail. A
smooth body (without engine cylinders) was also tested.
Test results are given in pounds drag of the models at sev-
eral air speeds up to 100 miles per hour.

APPARATUS AND METHODS

A description of the 20-foot propeller-research tunnel
and methods of testing may be found in reference 5. The
nacelles were supported by tubes attached to the regular
airfoil supports. (See fig. 1.) To these tubes were at-
tached short arms bolted to the end of the vertical sup-
ports. Suitable holes in the arms permitted the angle of
pitch to be adjusted to the desired values. With this ar-
rangement it was not necessary to use a sting and there-
fore the tare drag was reduced. In making the tare-drag
tests the nacelles were supported by wires free of the
tubes.

Figure 2 shows the nacelles used and gives their prin-
cipal dimensions. The larger nacelle had a maximum diameter
approximately equal to that of the engine. This nacelle
was tested both with the hood (ring) in place and with it
removed, the former arrangement constituting an N.A.C.A.
cowled nacelle. The conventional nacelle (hereafter called
small nacelle) had a small diameter back of the cylinders
and a little over half the fin area of the cylinders ex-
posed. This nacelle was tested with the cylinders exposed
and with the hood as previously used on the N.A.C.A. cowled
nacelle as well as with various forms of ring cowlings. A
smooth body without engine cylinders was also tested as it
had been used in the general program.

The various ring cowlings are shown in Figure 3 and are of two types. The first includes three wide, thin, fixed-angle rings designated Nos. 1, 2, and 3. The angles between the ring chords and the thrust lines are $0°$, $-3°$, and $-6.3°$, respectively. These rings were all of approximately 9-inch chord and the maximum thickness/chord ratio was approximately 0.05 for ring No. 1 and 0.07 for rings Nos. 2 and 3. All three of the rings were tested in the same two fore-and-aft positions on the engine and the $-6.3°$ ring was also tested in a more forward position. (See fig. 4 for ring positions.) Tests of these three fixed-angle rings agreed with flight tests (reference 4) in that the angle of chord to thrust line had a marked effect on the results obtained. The variable-angle ring as shown in Figure 3 was then constructed. This polygonal ring of nine sides had a 6-inch chord and a maximum thickness/chord ratio of approximately 0.10. The chord angle could be adjusted from $0°$ to $-15°$. The design of this ring was based on a study of the tests of reference 6.

The two positions in which the variable-angle ring was tested are given in Figure 4. In the rear position it was tested with the chord set $0°$, $-5°$, $-8°$, $-10°$, and $-15°$ to the thrust line. The $-8°$ setting was found to be the best and this angle only was used in the tests in the forward position.

All the combinations except one were tested at $-5°$, $0°$, $5°$, $10°$, and $15°$ angle of pitch. Figure 1 shows most of these combinations as mounted for tests. Readings were taken from which the dynamic pressure and drag could be obtained. Tare-drag tests at the above angles of pitch provided suitable data for computing the net drag.

RESULTS

The net drags of all the combinations tested are given in Tables I, II, and III at 50, 75, and 100 miles per hour for $-5°$, $0°$, $5°$, $10°$, and $15°$ angle of pitch. The results for 100 miles per hour are plotted in Figures 5 to 9, inclusive. Figures 7 and 9 show the effect on drag of the angle of the cowling-ring chord to the thrust line. Figure 10 gives the net drag, in pounds, of full-size Wright J-5 engine nacelles obtained by scaling up these model results. The relative drag of the different nacelles and engine cowlings at the three different air speeds is practically

the same; since the percentage accuracy is the greatest at
100 miles per hour, the discussion following has been tak-
en from the results at this speed only.

The results that are given have been taken from faired
curves and are believed to be accurate to within ±0.2
pound as the average deviation of the test points from the
faired curves did not exceed this amount.

DISCUSSION

Effect of Body Shape and N.A.C.A. Hood

Table I and Figure 5 give the results for the nacelles
exclusive of the ring cowlings tested on the small nacelle.
The following savings in drag were obtained at 0° angle of
pitch: increasing the diameter back of the engine cylin-
ders reduced the drag 25 per cent when the cylinders were
exposed and 57 per cent when a hood was used; using a hood
reduced the drag 39 per cent on the small nacelle and 65
per cent on the large one; increasing the diameter and us-
ing a hood (N.A.C.A. cowled nacelle) reduced the drag 74
per cent. With the following two exceptions, these savings
were practically independent of angle of pitch up to and
including 15°. When the hood was employed, enlarging the
diameter decreased the drag 43 per cent at 15° angle of
pitch as against 57 per cent at 0°. Likewise, if both the
diameter was increased and the hood was employed (N.A.C.A.
cowled nacelle), the drag relative to that of the small
nacelle with exposed cylinders was reduced only 62 per cent
at 15° as against 74 per cent at 0°. These results also
show that using the hood is more effective in reducing the
drag than increasing the diameter behind the cylinders and
that increasing the diameter behind the cylinders is more
effective when a hood is employed than when the cylinders
are exposed. These results are in agreement with the full-
scale tests of references 2 and 3.

The drag of the smooth body was 8.6 pounds at 0° pitch.
This value seems rather excessive as it is practically the
same as the drag of a sphere whose diameter is equal to
the maximum diameter of the body. An examination of Figure
2 reveals the fact that although this body is by no means
an ideally streamline shape, one would hardly expect it to
have as high a drag as that measured.

Effect of Rings

There is a popular belief that almost any kind of a ring cowling will reduce the drag of a radial engine. The fallacy of this belief for the condition without a propeller is shown by the results obtained with rings Nos. 1 and 2 and with the variable-angle ring set 0. At 0 angle of pitch these rings increased the drag over that with the cylinders exposed. Ring No. 3 in the best location reduced the drag 7.5 pounds or 25 per cent. The effect of the fore-and-aft position of the rings is shown in Figure 6 and it will be observed that moving the ring forward increased the drag with rings Nos. 1 and 2, and reduced the drag with ring No. 3. Figure 7, in which the values of drag are replotted to show the effect of ring-chord angle to the thrust line for the three rings in position No. 3, shows that further reduction could be expected if the ring-chord angle were increased. These results, which are also given in Table II, indicate that the fore-and-aft location of the ring affects the drag to a slight extent but that the angle of the ring chord to the thrust line is a more decisive factor in drag reduction.

The results with the variable-angle ring will be found in Table III and Figures 8 and 9. In the rear position the optimum angle of chord increased with the angle of pitch as shown in Figure 9. The -8° chord angle was selected and run in the forward position where the drag was found to be slightly lower than in the rear one. (See Table III and fig. 8.) With this optimum angle and position the drag was reduced 38 per cent over that with the cylinders exposed. None of the other angles were tried in the forward position.

Comparison of Rings and N.A.C.A. Hood

The following comparison is made between the rings and the N.A.C.A. Hood which was tested on the small nacelle as a matter of interest. With the hood, and the rings in position No. 1, the leading edge of the cylinder cowling was 5-3/4 inches ahead of the center line of the cylinders. (See figs. 2 and 4.) This was the maximum forward location that could be used and have clearance for the propeller at high pitch settings. With the variable-angle ring set -8° in position No. 1 the drag was 18.7 pounds at 0° angle of

pitch, which is only 0.2 pound higher than with the hood;
therefore, there is little choice between the two for
cruising or high speed. However, the drag increased more
rapidly with the ring than with the hood as the angle of
pitch was increased until at 15° it was almost $1\frac{1}{2}$ times
that with the hood. Hence the hood appeared to be the bet-
ter cowling for general-purpose use. Subsequent tests of
wing-nacelle combinations have verified this both with the
propeller operating and with it removed. (Reference 1.)

Since tests with the small nacelle showed that the
N.A.C.A. hood was superior to all of the rings tested,
the rings were not tested on the large nacelle.

Effect of Angle of Pitch

All the combinations show the usual increase in drag
with angle of pitch. A systematic analysis reveals the
interesting fact that the lower the drag of the combination
at 0° pitch the higher is the percentage increase in drag
as the angle of pitch is increased. The combination which
had the lowest drag at 0° pitch had, however, the lowest
drag throughout the entire pitch range.

Agreement with Full-Scale Tests

The full-scale drags at 0° angle of pitch of all the
combinations tested as obtained by scaling up these model
tests are given in Figure 10. Results of some previous
full-scale wind-tunnel drag tests on J-5 engine nacelles
are given in reference 3. The following table giving the
drag (in pounds) at 100 miles per hour shows a close agree-
ment between the 4/9-scale model tests reported herein and
those full-scale tests.

Nacelle	Full-scale drag ref. 3 pounds	Model drag $(4/9)^2$ pounds
Small nacelle - exposed cylinders	155	153
N.A.C.A. nacelle	43	40

Other Considerations

In the general program of wing-nacelle-propeller in-
terference, propeller tests, especially with tandem pro-
pellers, have shown that the propulsive efficiency is af-
fected by the angle of the ring chord to the thrust line.
This effect is presumably caused by the fact that the
slipstream of the propeller changes the direction of air
flow over the ring and consequently the drag. It has been
found that the cowling that gives the lowest drag without
the propeller is not always the best combination when used
with a propeller. This is a partial explanation of why
some cowlings have been known to increase the drag with
the propeller removed in tunnel tests but have shown in-
creases in speed when tested in free flight. At least it
is evident that a nacelle cowling should not be selected
entirely from a consideration of drag and that it is nec-
essary to consider the complete power unit including na-
celle and propeller.

Langley Memorial Aeronautical Laboratory,
    National Advisory Committee for Aeronautics,
        Langley Field, Va., September 22, 1932.

REFERENCES

1. Wood, Donald H.: Tests of Nacelle-Propeller Combinations in Various Positions with Reference to Wings. II. Thick Wing - Various Radial-Engine Cowlings - Tractor Propeller. T.R. No. 436, N.A.C.A., 1932.

2. Weick, Fred E.: Drag and Cooling with Various Forms of Cowling for a "Whirlwind" Radial Air-Cooled Engine-I. T.R. No. 313, N.A.C.A., 1929.

3. Weick, Fred E.: Drag and Cooling with Various Forms of Cowling for a "Whirlwind" Radial Air-Cooled Engine-II. T.R. No. 314, N.A.C.A., 1929.

4. Gough, Melvin N.: Effect of the Angular Position of the Section of a Ring Cowling on the High Speed of an XF7C-1 Airplane. T.N. No. 355, N.A.C.A., 1930.

5. Weick, Fred E., and Wood, Donald H.: The Twenty-Foot Propeller Research Tunnel of the National Advisory Committee for Aeronautics. T.R. No. 300, N.A.C.A, 1928.

6. Townend, H. C. H.: Reduction of Drag of Radial Engines by the Attachment of Rings of Aerofoil Sections, Including Interference Experiments of an Allied Nature, with Some Further Applications. R. & M. No. 1267, British A.R.C., 1929.

TABLE I. Net Drag of Various Nacelles
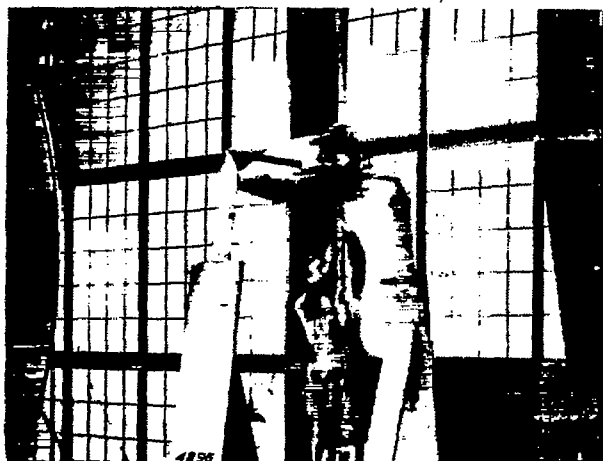(Values in pounds)

Angle of pitch degrees	Smooth body	Small nacelle with exposed cylinders	Small nacelle with N.A.C.A. hood	Large nacelle with exposed cylinders	Large nacelle with N.A.C.A. hood
q = 6.4 lb./sq.ft., 50 m.p.h.					
-5	1.9	8.6	4.6	--	3.8
0	2.2	7.8	4.6	6.0	2.2
5	2.2	8.5	5.5	6.0	2.5
10	2.6	9.0	6.1	7.0	3.1
15	3.0	9.6	6.4	-	4.0
q = 14.4 lb./sq.ft., 75 m.p.h.					
-5	4.2	18.7	10.9	-	4.9
0	4.9	17.1	10.4	13.5	4.6
5	4.9	17.7	10.9	13.3	5.3
10	5.8	18.9	12.0	15.1·	6.0
15	8.0	19.9	13.1	-	7.6
q = 25.6 lb./sq.ft., 100 m.p.h.					
-5	7.3	33.2	19.9	-	7.2
0	8.6	30.2	18.5	22.8	7:9
5	8.8	30.9	18.6	23.4	8.4
10	10.4	33.0	20.3	25.5	9.4
15	14.3	34.3	22.6	-	12.9

TABLE II. Net Drag of Small Nacelle
with Fixed-Angle Rings
(Values in pounds)

Angle of pitch degrees	Ring No. 1		Ring No. 2		Ring No. 3		
	Pos. No. 2	Pos. No. 3	Pos. No. 2	Pos. No. 3	Pos. No. 1	Pos. No. 2	Pos. No. 3
	q = 6.4 lb./sq.ft., 50 m.p.h.						
-5	10.0	10.4	8.2	8.2	7.0	6.6	7.1
0	10.5	9.7	7.6	7.8	6.0	6.0	6.3
5	10.5	9.5	7.3	8.0	6.0	6.3	6.9
10	10.8	9.5	8.2	8.4	7.0	7.7	7.9
15	10.9	10.2	9.0	9.1	8.6	8.8	9.6
	q = 14.4 lb./sq.ft., 75 m.p.h.						
-5	22.1	22.1	18.6	18.4	15.2	14.9	15.5
0	22.5	21.4	17.6	17.5	13.0	13.5	14.0
5	22.7	21.3	17.6	17.5	13.3	14.3	15.9
10	22.3	21.3	18.5	18.2	15.5	16.6	17.5
15	23.4	22.7	20.2	20.5	18.5	19.5	20.5
	q = 25.6 lb./sq.ft., 100 m.p.h.						
-5	38.6	38.5	33.0	32.6	26.7	26.6	26.5
0	39.1	37.5	32.6	31.1	22.7	23.8	24.9
5	37.6	37.5	31.5	30.9	23.5	25.3	27.0
10	38.2	36.8	32.7	32.2	27.5	28.8	30.1
15	40.4	40.0	36.1	36.5	32.4	33.9	35.7

TABLE III. Net Drag of Small Nacelle
with Variable-Angle Ring
(Values in pounds)

| Angle of pitch degrees	Pos. No. 1 Set $-8°$	Position No. 2				
		Set $0°$	Set $-5°$	Set $-8°$	Set $-10°$	Set $-15°$
$q = 6.4$ lb./sq.ft., 50 m.p.h.						
-5	5.6	8.9	6.1	6.0	5.6	6.9
0	5.2	8.5	5.0	5.5	5.5	6.4
5	5.7	8.9	5.9	5.6	5.4	6.9
10	6.6	8.3	6.7	7.5	6.5	6.5
15	7.8	9.3	8.4	8.4	8.1	8.1
$q = 14.4$ lb./sq.ft., 75 m.p.h.						
-5	12.5	19.8	13.4	12.5	12.6	6.9
0	10.9	20.0	11.0	11.5	11.6	6.4
5	11.6	19.3	13.1	12.4	11.9	6.9
10	14.5	18.4	15.4	15.1	13.9	6.5
15	17.4	20.5	18.2	18.1	17.3	8.1
$q = 25.6$ lb./sq.ft., 100 m.p.h.						
-5	21.1	34.9	22.7	21.9	22.9	26.0
0	18.7	36.1	19.0	19.8	20.1	25.2
5	19.9	33.7	23.3	21.8	20.8	25.1
10	25.6	32.5	27.5	25.5	24.2	25.7
15	30.5	36.4	32.0	31.7	30.6	30.4

A, Small nacelle with exposed cylinders
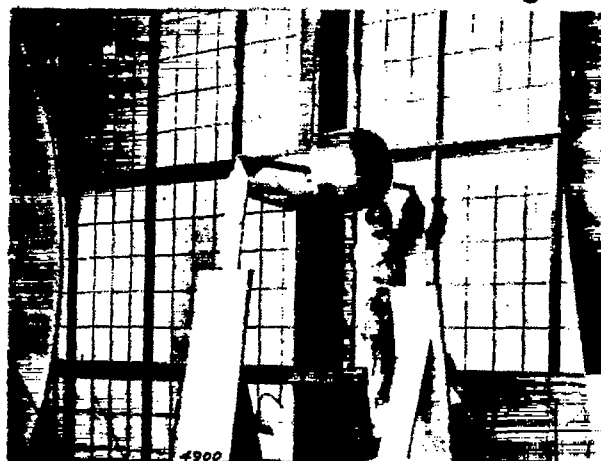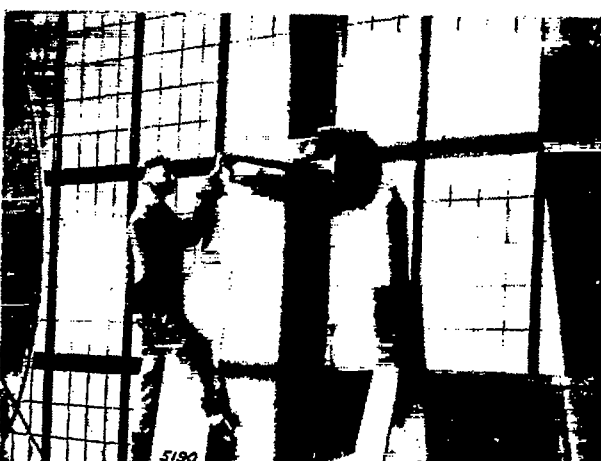

B, Small nacelle with N.A.C.A. hood

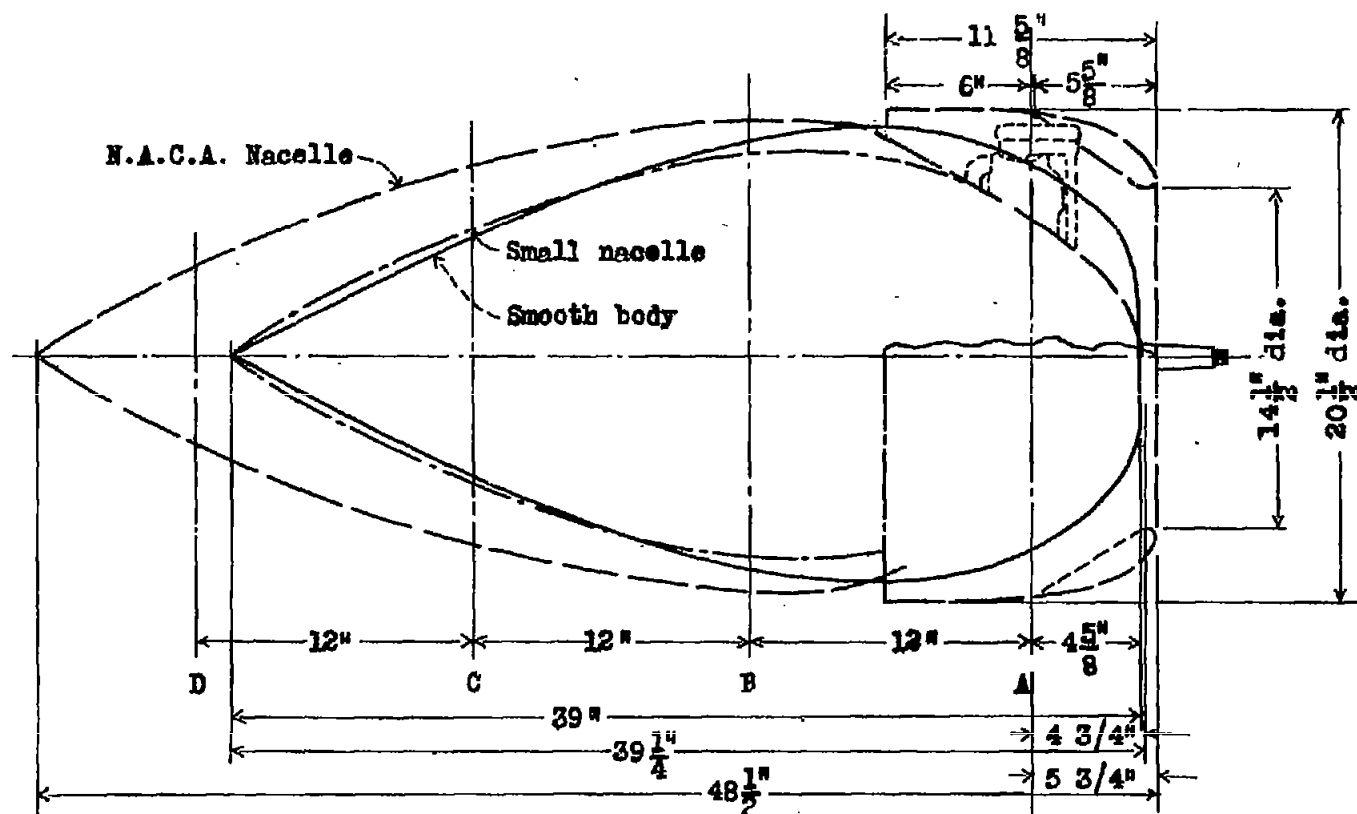C, N.A.C.A. nacelle with hood cowling removed
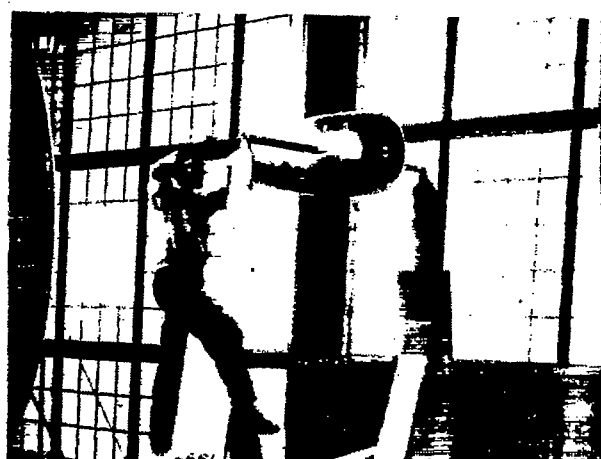
D, N.A.C.A. nacelle

E, Small nacelle with variable-angle ring

F, Small nacelle with ring No.3 in position No.2

Fig. 1

Diameter - inches					
	Sta.A	Sta.B	Sta.C	Sta.D	Max.
Small nacelle	11 1/2	16 5/8	10 1/2	—	16 3/4
N.A.C.A. nacelle	11 1/2	19 3/8	15 3/4	7 1/2	19 1/2
Smooth body	15	17 3/4	9 3/4	—	19

Note: Dummy engine not used
with smooth body.

Fig. 2

Fig. 2

Fig.3 Ring cowlings.

$5\frac{1}{4}''$ — Pos. No. 1

$4\frac{1}{4}''$ — Pos. No. 2

$3\frac{1}{4}''$ — Pos. No. 3

Fixed angle rings

Cylinders

Variable angle ring

$5\frac{3}{4}''$ — Pos. No. 1

$4\frac{3}{4}''$ — Pos. No. 2

Fig. 4

×——————— N.A.C.A. nacelle

+——————— Smooth body

○——————— Small nacelle,with N.A.C.A. hood

□——————— N.A.C.A. nacelle,hood removed

△——————— Small nacelle,exposed cylinders
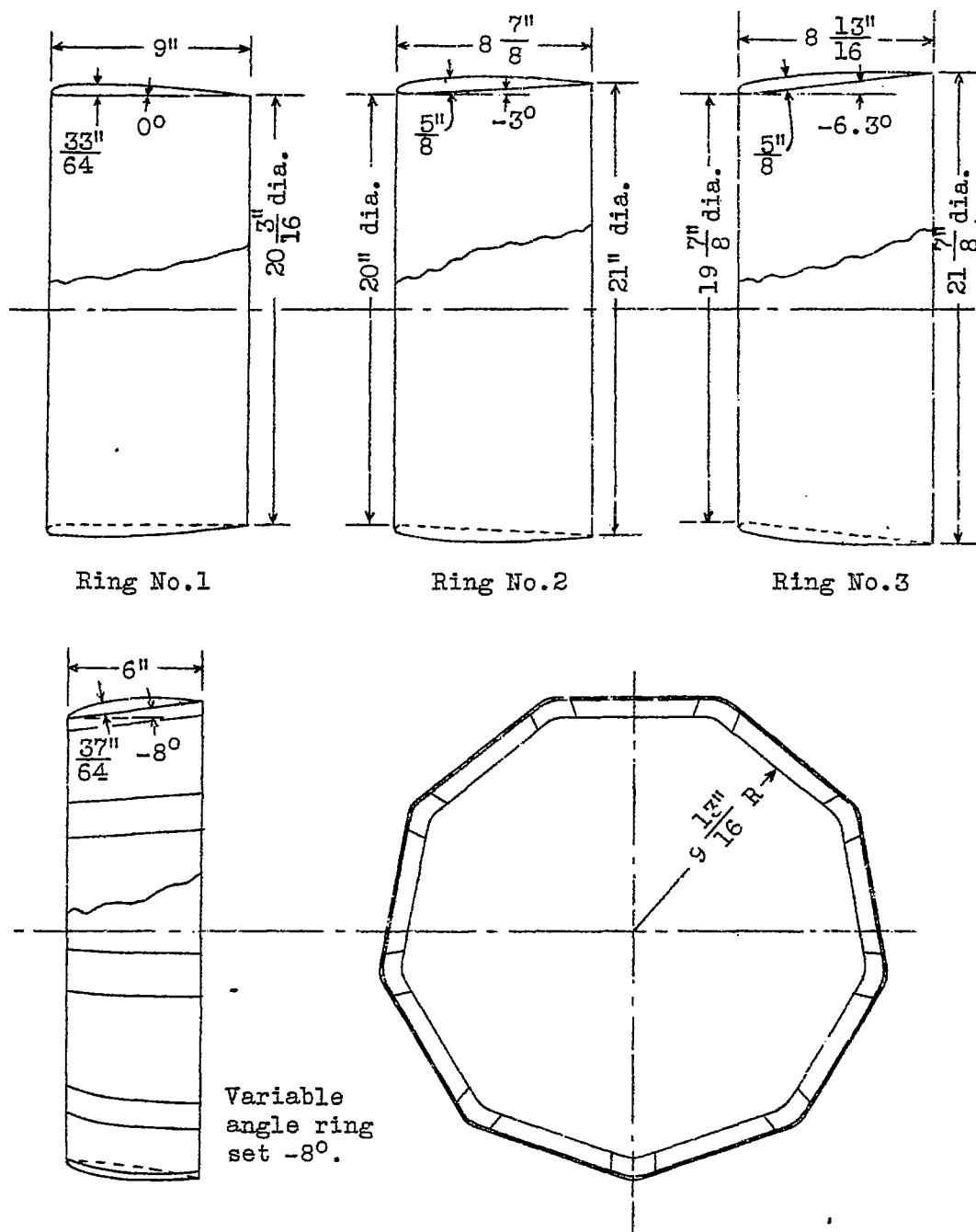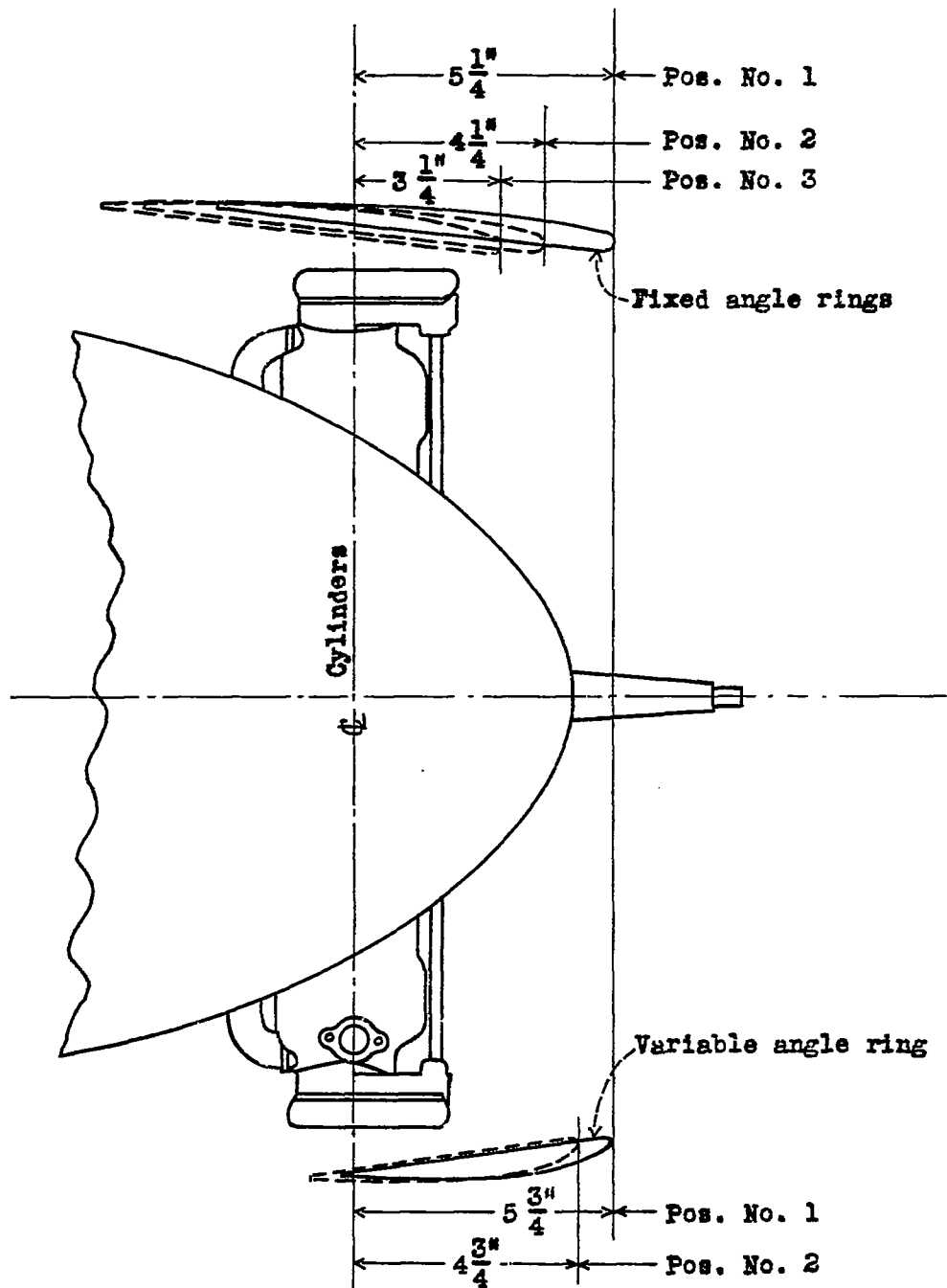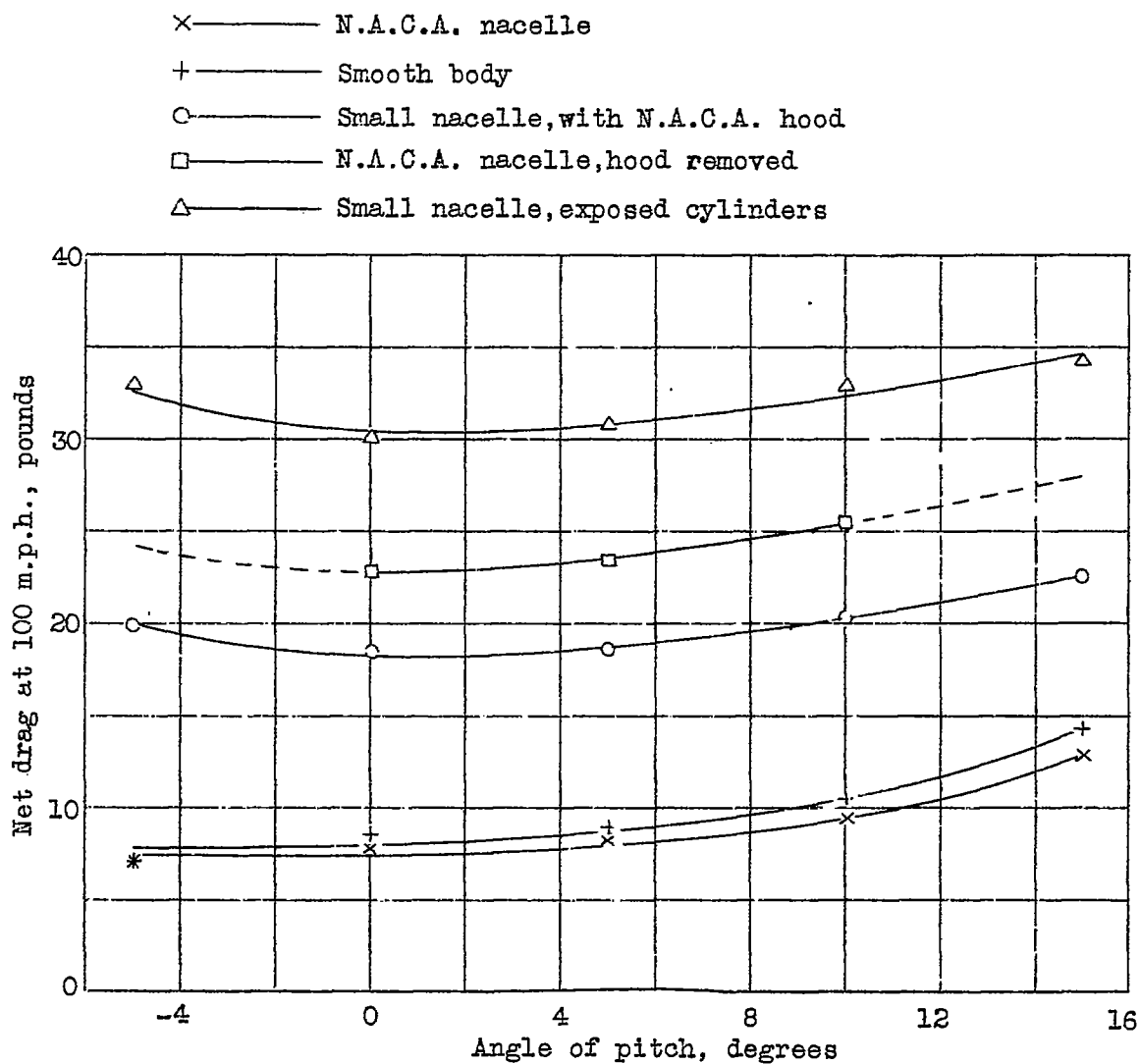
Fig.5 Change in drag with angle of pitch. (Various nacelles)

a, Ring No.1 (0°)
b, " No.2 (-3°)
c, " No.3 (-6.3°)

□————— Position No.1
×————— " No.2
○————— " No.3
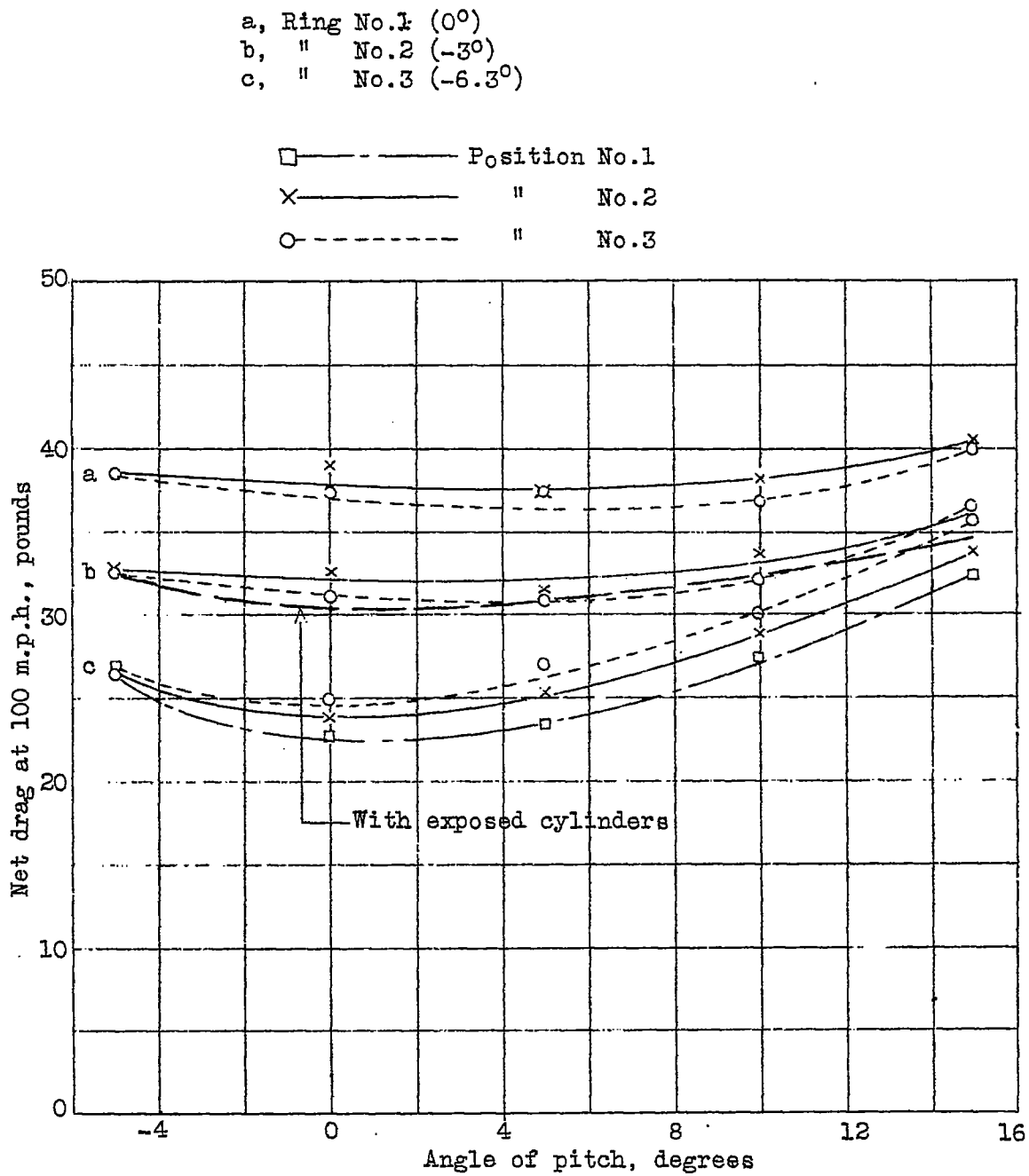
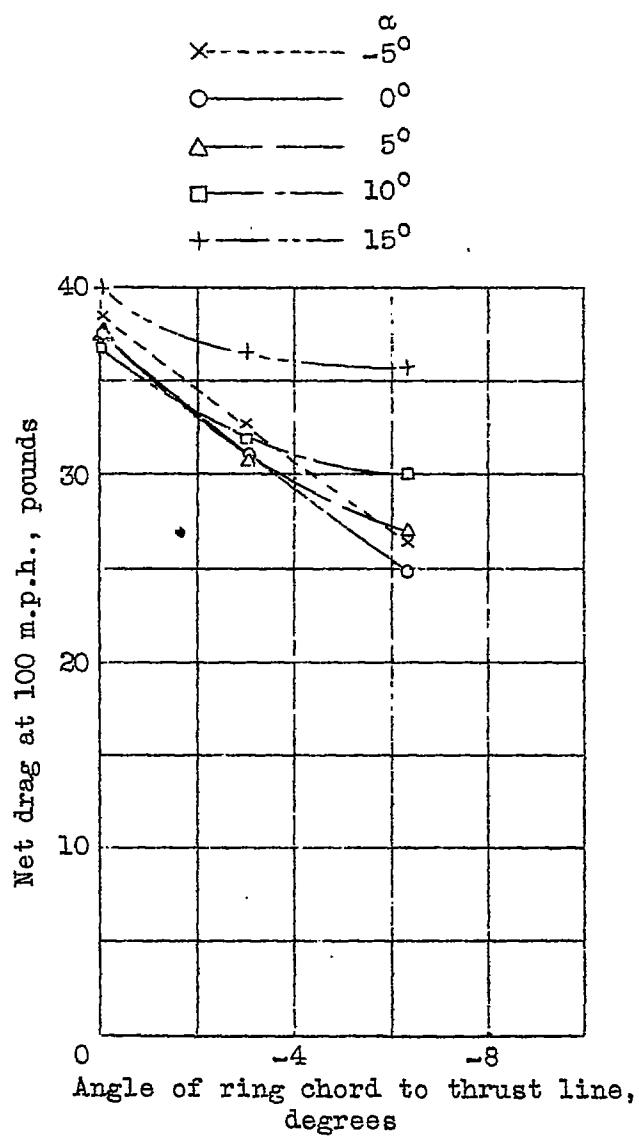Fig.6 Drag of small nacelle with three fixed-angle rings in three
       positions.

Fig.7   Effect of angle of chord to thrust line on drag. (Small nacelle
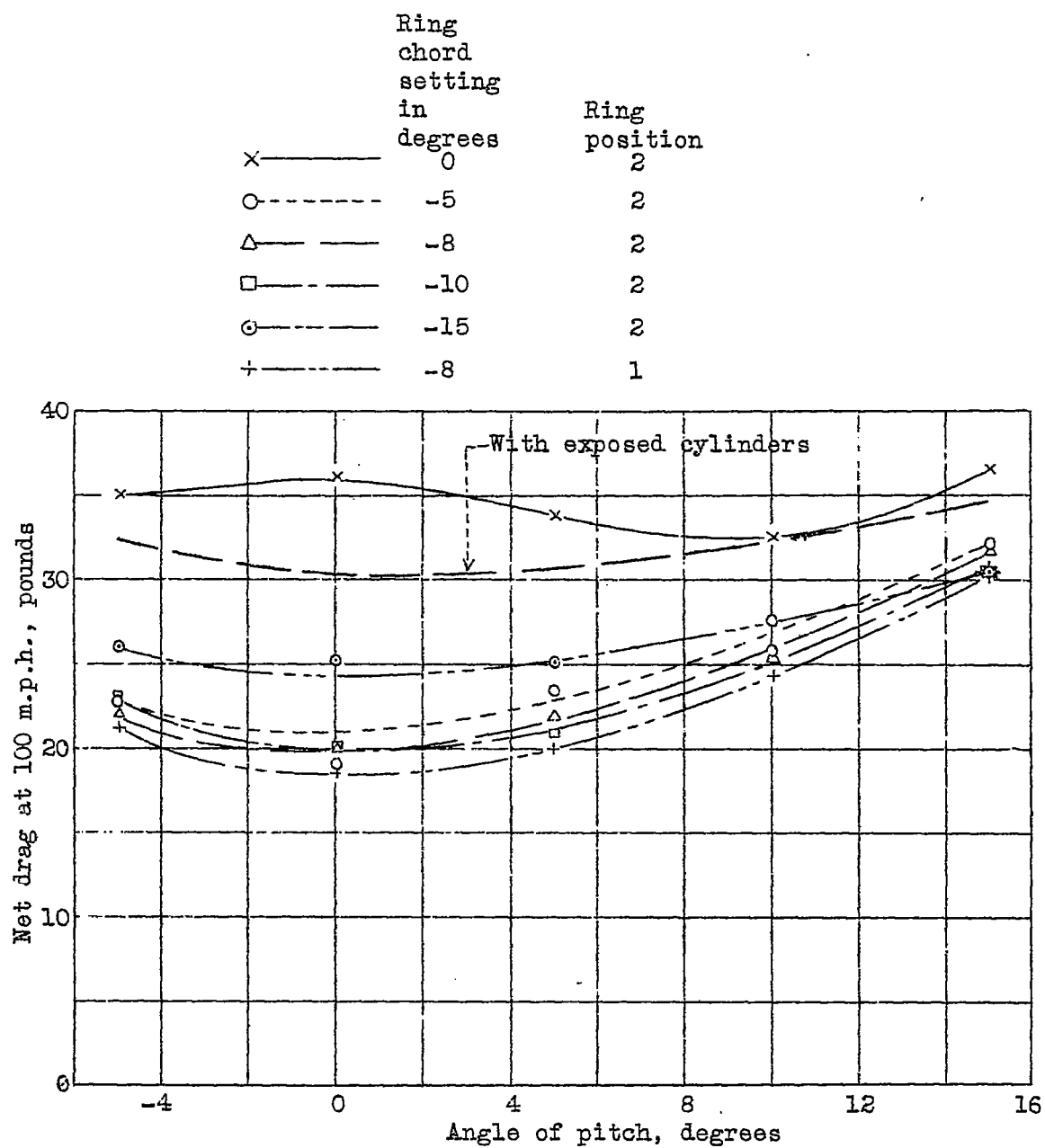   with rings Nos.1,2, and 3 in position No.2).

		Ring chord setting in degrees	Ring position
✕———————		0	2
○- - - - - - -		−5	2
△—— —— ——		−8	2
□——— · ———		−10	2
⊙—— ·· ——		−15	2
+——— ·· ———		−8	1

Fig.8 Change in drag with angle of pitch. (Small nacelle with variable-
angle ring.

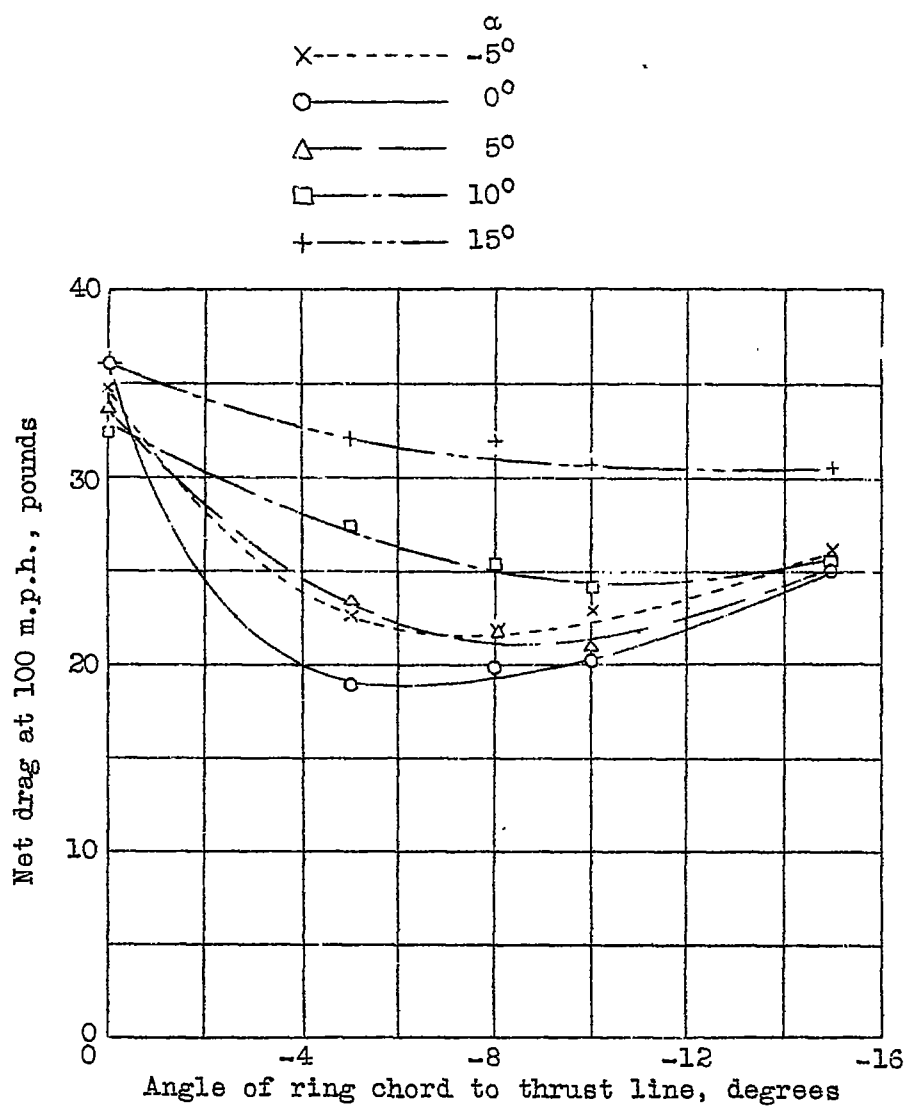Fig.9 Effect of angle of chord to thrust line on drag. (Small nacelle
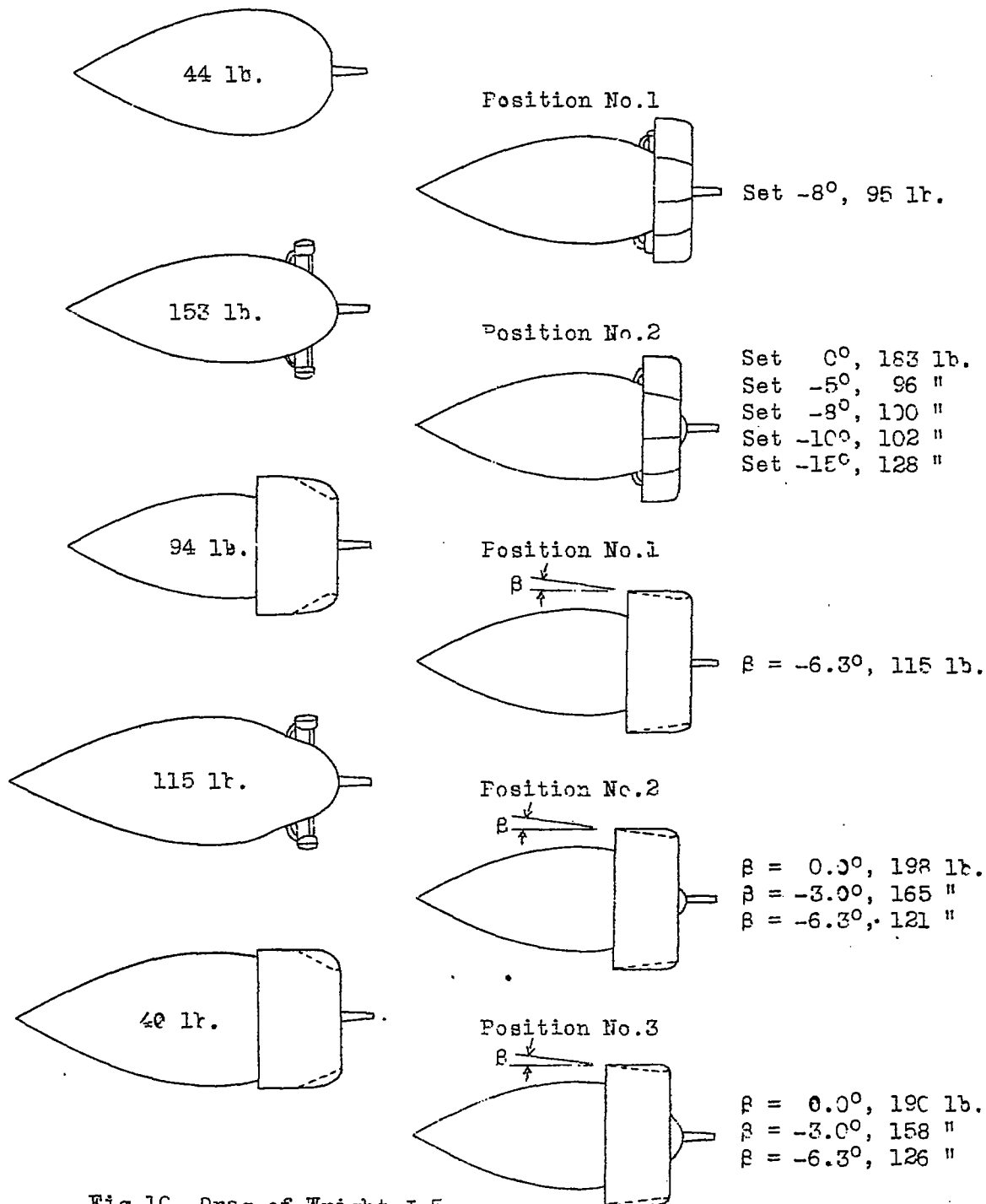with variable-angle ring in position No.2

Fig.10   Drag of Wright J-5
         engine nacelles.
(Drag at 100 m.p.h. - scaled up from 4/9-scale model tests).